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STUDY ON THE EFFECT OF NANO SILICA ON MECHANICAL PROPERTIES OF CONCRETE

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ABSTRACT

Objectives: Increasing the usage of fly ash in concrete helps in: i) Improving the strength of concrete with colloidal Nano silica in concrete ii) reducing the pollution of environment caused by Carbon-di-oxide emitted from cement industries.

Novelty of the Study: At present, studies on Nanotechnology and Nano materials are emerging and more profound research on nanoparticles like Nano silica, Nano alumina, Nano iron oxide etc., is carried out. In this work, the impact of colloidal form of Nano size particles of silica used in concrete in the modification of the properties of concrete was studied. The concrete strength was improved due to the Nano size particles which filled the voids in between the micron size cement particle by its more specific surface area, and therefore a denser concrete was being achieved.

Methods/Analysis: since two decades, numerous explorative works have been done utilizing Nano materials, such as Nano silica, Nano alumina etc., to accomplish a high strength and to increase the durability of concrete. On the principle of environmental sustainability, fly ash is used for fractional substitution of cement. The present work concentrates principally towards the addition of silica Nano particles in colloidal form with the reference concrete mix. The cement was replaced with fly ash at 30%, 50% and 75% in concrete mixture. In addition to this 1% and 2% of Nano silica was used in concrete to enhance the properties of concrete. Various tests were conducted in order to obtain the modulus of elasticity, compressive strength and split tensile strength of the improved concrete. Results show that the incorporation of the Nano silica in concrete increases the mechanical properties of concrete.

Key words: Nano materials, Nano silica (nS), Dispersion, Agglomerates, Silica fines.

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1. INTRODUCTION

The construction industries are presenting numerous new and propelled materials for the development of structures. Cement is one of the commodities used in large quantities for the structures, yet increasing the cement production leads to environmental pollution. The essential strategy is to reduce the cement quantity in concrete, to replace cement with other materials having pozzolanic nature such as silica fume or micro silica and Nano silica, thereby reducing pollution of environment. The use of nS and its impact in concrete is not yet completely analysed. This study intends to display the significance of nS applications in cement concrete and to concentrate on the nS properties to render the appropriateness in concrete. Only very few studies have been carried out on the usage of Nano silica and fly ash in concrete. Many research works were carried out using Nano materials but the works on combination of fly ash and Nano materials are very less.

Calcium silicate hydrate formed by good pozzolanic nature of silica fume reacts with Ca $(OH)_2$. Stronger concrete with minimum pores can be achieved by the hydrate present in the interfacial zones between the cement paste and aggregates. Specific surface area of silica fume is 25 m^2/gm, which is 80 times more than ordinary Portland cement. The size of Nano silica particles which is lesser than silica fume increases the surface area and reduces the pores giving a stronger mix of concrete. There is no much considerable effect on the characteristics of cement by the blending of cement and silica fume. Water absorption and compressive strength test were conducted using the Nano silica prepared by sol-gel method. (6) and (1). Agglomerates of silica particles developed from pyrogenic silica powder are less than colloidal Nano silica, this act as filler and helps more effectively in developing Calcium silicate hydrate gel. At initial days, colloidal form of Nano silica in concrete gives more compressive strength than powder form of Nano silica, but on later ages both colloidal as well as powder Nano silica will give equal strength (2).

Fly ash play an important role in reducing the pollution caused due to cement production. Strength of mortar can be enhanced by adding Nano silica and fly ash by high temperature curing (3). Analysis made for effective dispersion of Nano particles in concrete mixes states that it will give better mechanical and durable strength resulting in high performance concrete. The performance of concrete with Nano material, silica fumes and fly ash were investigated to obtain compressive strength, concrete chloride diffusivity, sulphate resistance and drying/wetting cycle in corrosive environments. (4) and (10).

The works of above stated researchers concentrate mainly on improving the concrete strength and thermal insulation and effectiveness of anti-corrosion coatings by nanoparticles. The four different grades of concrete from M20 to M50 were prepared using Nano fly ash. Their workability property and compressive strengths were tested. The results revealed that Nano fly ash added concrete is more effective than the conventional concrete. (5) and (8). Taguchi method of design of experiment were used to reduce the number of trials by optimizing the strength. High strength self-compacting concrete was analyzed by using L18 orthogonal array (7).

Optimum content of mix proportion for self-compacting concrete was arrived 1 part of silica fume and 2 parts of fly ash. The quantity of ultra-fine amorphous silica in concrete is equivalent to 25% of silica fume(9). 6% of micro silica and 1.5% of Nano silica is optimum content concluded by (12). Partial replacement of cement by Nano silica increases the electrical resistance and the compressive strength. The study of alkali-silicate reaction, hydration process, reactiveness of fly ash in concrete and improving the concrete properties and understanding the structure at Nano scale by conducting the experiments results in (11).

Ground granulated blast furnace slag and silica Nano particles in concrete mixture show less impact. But at later ages, 40% of physical and mechanical strength got improve. Split

tensile strength decreases with the increasing of the SiO_2 Nano particles. It improves the pore structures and increases the strength of concrete (13). The SiO_2 Nano particles imparts more strength than the blend of cement and silica fume used in mortar. Compressive strength of mortar was increased by using the SiO_2 Nano particles when used at various percentages such as 3%, 6%, 9% and 12% for water / binder ratio of 0.23 to 0.48. Nano SiO_2 gives better strength than silica fume and conventional concrete.

The SiO_2 Nano particles not only act as a filler to improve the microstructure and also activate the pozzolanic reaction. (14). The studies were made in laboratory on six different concrete mixtures in which three were using 30% fly ash added by replacing the cement, while other 3 mixtures were conventional cement concrete. Colloidal Nano silica with normal ingredients of concrete with fly ash on one hand and without fly ash on the other hand are compared and analysed. The influence of colloidal Nano silica on the properties of concrete such as permeability, compressive strength and other mechanical properties were studied. The results show that Nano silica and fly ash in concrete improves the reactivity thereby increasing the strength (15). Images of scanning probe microscope and Nano indentation help in analysing the properties of cement with replacement of cement by 0% and 15% of silica fume. Addition of Nano silica significantly increases the calcium silicate hydrate gel with high stiffness was noticed in the study using Nano indentation. Nano silica of 18% in concrete increases the 50% Calcium silicate gel that is formed with high stiffness. The C-S-H gel formation is the twice more in concrete mix when the silica Nano particles are used. In this study, the effects of silica fume and Nano silica in concrete were compared. Hence, the incorporation of Nano silica make a positive impact on high stiffness of C-S-H, durability and high resistance of calcium leaching (16).

In the area of research on concrete materials by the National Research Council, Canada. The improvement in properties of concrete by changing the micro structures of cement hydration is proved. Nanotubes and Nano particles incorporation is the key to enhance the functionality (17). Nano particles give a negative impact in the strength properties of concrete when Nano SiO_2 used with ground granulated blast furnace slag in self-compacting concrete. At later ages, GGBFS in concrete increases up to 45%. Optimum amount of Nano particle which was used in this study is 3% and average particle size was 15 nm. It improves the C-S-H gel formation and the amount of calcium hydroxide in the early days. The strength improvement and the resistance to water permeability of concrete were achieved to a greater extent (18).

2. MATERIALS AND METHODS

Cement conforming to IS 8112:1989, Ordinary Portland cement 43 grade was used as a binding material and sand conforming to IS 383:1970 was used as the fine aggregate in the mix. A water/ binder ratio of 0.5 and a cement content of 380 kg/m^3 were used for M_{30} grade of concrete. The content of fine aggregate 692 kg/m^3 and coarse aggregate 1266 kg/m^3, respectively were maintained. Specimens were prepared with Ordinary Portland Cement and aggregates with mix proportion of 1:1.82:3.33 was used.

In addition 1% of superplasticizer (Acrylic polymer), Nano Silica content of 1% and 2% were also used in concrete. The moulds were filled with concrete and compacted by a table vibrator to ensure that no large air voids are formed and proper compaction was achieved. After 24 ± 4 h, the cube specimens were demoulded and were immersed in water for curing. Conventional concrete cubes, cylinder specimens were tested in compression testing machine to find compressive strength, split tensile strength, modulus of elasticity values of concrete at various ages of curing such as 28,56 and 90 days. 2% of Nano SiO_2 was added with concrete for finding modulus of elasticity using the cylinders (150mm diameter, 300mm length).

Cylinder specimens were tested in compression testing machine for compressive strain values. The specific gravity of all the materials are given in Table1. The concrete for micro structure analysis using Scanning Electron Microscopy (SEM) are given in Figures 7-9.

Table 1 Specific gravity of materials used

SL.No.	Materials	Specific gravity
1	Cement	3.16
2	Fly ash	2.74
3	Nano silica	1.22
4	Acrylic polymer	1.19
5	Sand	2.60
6	Coarse aggregate	2.80

3. EXPERIMENTAL RESULTS AND DISCUSSION

Addition of Nano silica in concrete improves the strength by filling the micro pores and making a dense concrete. The combined effect of Nano silica and fly ash in concrete achieves more compressive strength and split tensile strength than conventional concrete. Replacement of cement by fly ash reduces the cost as per economical consideration and reduces the cement quantity in concrete, thereby reducing the cement production and hence reducing the pollution and saving the environment. Compressive strength values obtained from different trials are given in Table.2, Split tensile strength results are given in Table. 3.

Table 2 Compressive strength of M30 grade of concrete (N/mm^2)

Sl. No.	Trial ID	Description	at 28 days	at 56 days	at 90 days
1	C	Conventional concrete	38.60	39.90	41.63
2	I	Concrete with 1% nS	43.28	46.10	51.27
3	II	Concrete with fly ash 30%	38.60	43.30	47.00
4	III	Concrete with fly ash 50%	35.53	36.33	40.10
5	IV	Concrete with fly ash 75%	29.40	36.87	37.70
6	V	Concrete with fly ash 30% + 1% nS	40.90	45.97	50.16
7	VI	Concrete with fly ash 50% + 1% nS	37.95	39.55	45.75
8	VII	Concrete with fly ash 75% + 1 % nS	36.20	40.50	43.75

Table 3 Split tensile strength of M30 grade of concrete (N/mm^2)

Sl. No.	Trial ID	Description	at 28 days	at 56 days	at 90 days
1	C	Conventional concrete	3.13	3.82	3.89
2	I	Concrete with 1% nS	4.56	4.72	5.20
3	II	Concrete with fly ash 30%	2.53	3.09	3.96
4	III	Concrete with fly ash 50%	2.45	2.66	2.94
5	IV	Concrete with fly ash 75%	2.34	2.50	2.70
6	V	Concrete with fly ash 30% + 1% nS	4.06	4.34	4.77
7	VI	Concrete with fly ash 50% + 1% nS	3.52	3.78	4.25
8	VII	Concrete with fly ash 75% + 1 % nS	3.10	3.68	3.95

Table 4 Modulus of elasticity for various concrete mixture without Nano silica (N/mm^2)

S. No.	Description	at 28 day x10^4	at 56 days x10^4	at 90 days x10^4
1	Conventional concrete	3.39	3.53	3.88
2	Concrete with 30% cement replacement by fly ash	3.16	3.25	3.59
3	Concrete with 50% cement replacement by fly ash	3.05	3.49	3.53
4	Concrete with 75% cement replacement by fly ash	2.91	3.13	3.35

Table 5 Modulus of elasticity for various concrete mixtures with Nano silica (N/mm^2)

S.No.	Description	at 28 day x10^4	at 56 days x10^4	at 90 days x10^4
1	Conventional concrete + 2% nS	4.95	7.49	11.20
2	Concrete with 30% cement replacement by fly ash + 2% Nano silica	3.95	8.29	9.09
3	Concrete with 50% cement replacement by fly ash + 2% Nano silica	3.52	4.93	8.63
4	Concrete with 75% cement replacement by fly ash + 2% Nano silica	1.89	4.26	6.39

Modulus of elasticity of concrete reduces with the increasing of fly ash content in concrete, but modulus of elasticity of concrete was increased significantly when Nano silica and fly ash were added together in concrete, Modulus of elasticity of concrete is almost equal in both the cases: (i) 2% of Nano silica in concrete, (ii) 2% of Nano silica with 30% of fly ash. The results of the test on modulus of elasticity of conventional concrete and Nano concrete are tabulated in Table.4 and 5.

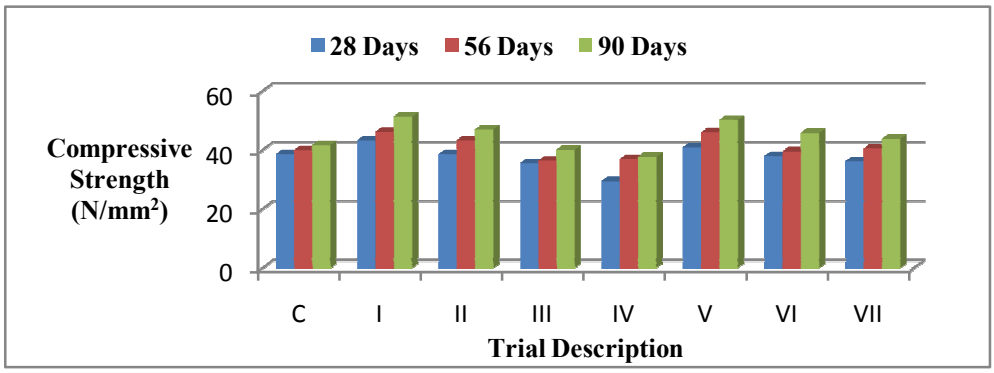

Figure 1 Compressive strength of concrete with Nano silica and Fly ash

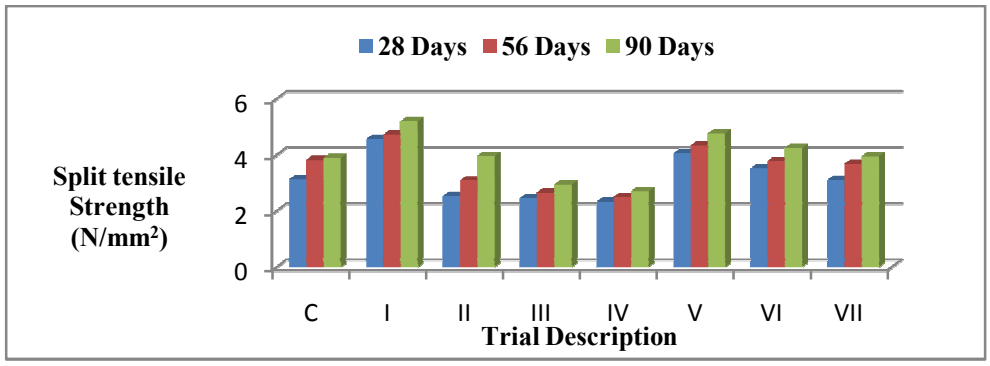

Figure 2 Split tensile strength of concrete with Nano silica and Fly ash

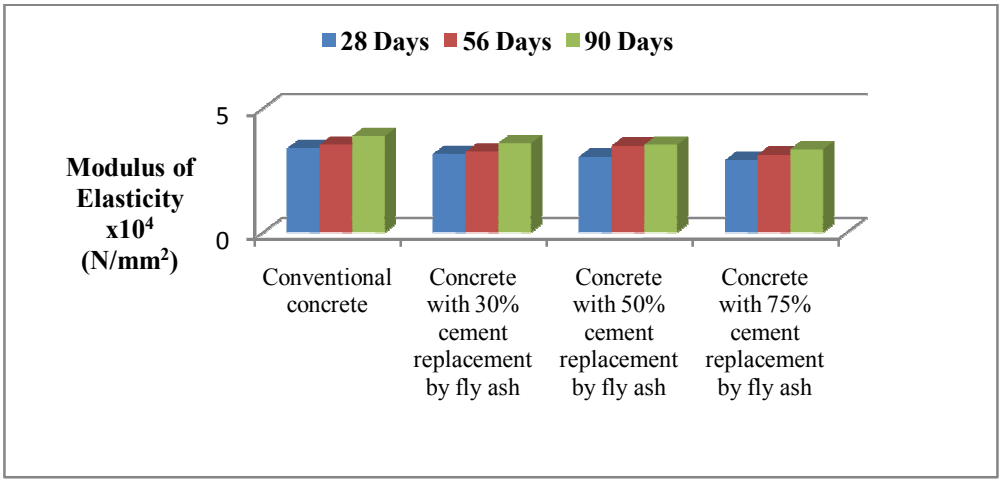

Figure 3 Modulus of elasticity of conventional concrete with various % of cement replacement by fly ash

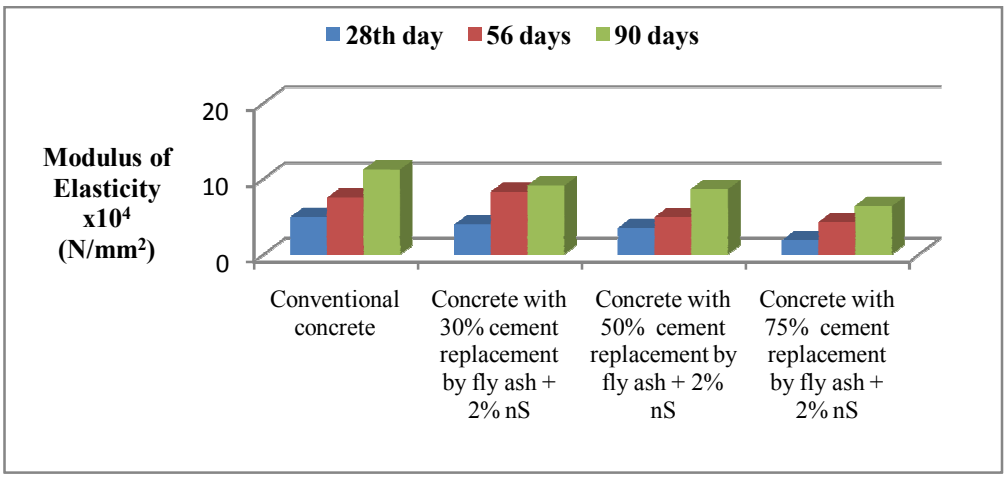

Figure 4 Modulus of Elasticity of conventional concrete with 2% nS and various % of cement replacement by fly ash

Fig.3 and Fig. 4 show the comparison of modulus of elasticity values for normal M30 grade concrete with and without Nano concrete, respectively. It clearly shows that the maximum load (100 kN) taken by the normal concrete is less than Nano concrete (170 kN). Modulus of elasticity is more due to higher specific surface area of Nano particle which gives a denser concrete with less pores reducing the strain when compared with the normal concrete. Nano concrete carry more load than normal concrete without any cracks or failure. Fig. 5 and Fig. 6 show the load Vs deflection curve for normal concrete and nano concrete, respectively.

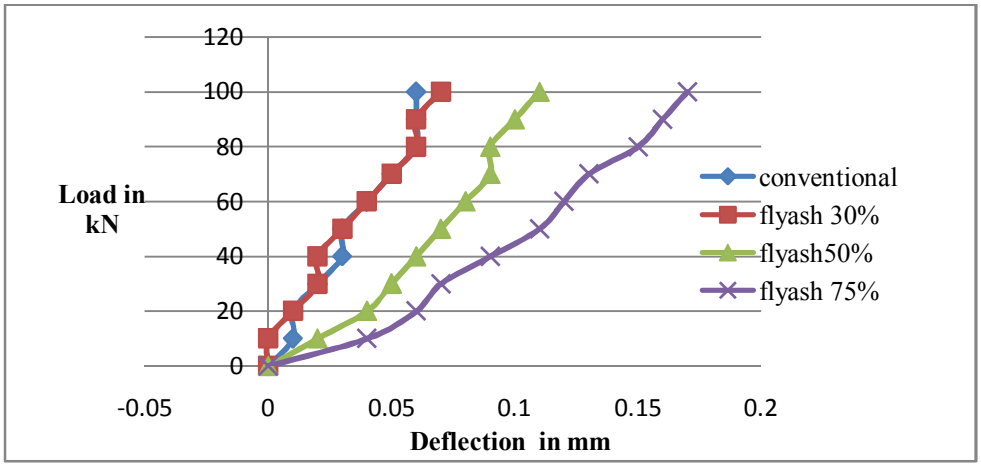

Figure 5 Load vs Deflection curve without Nano silica

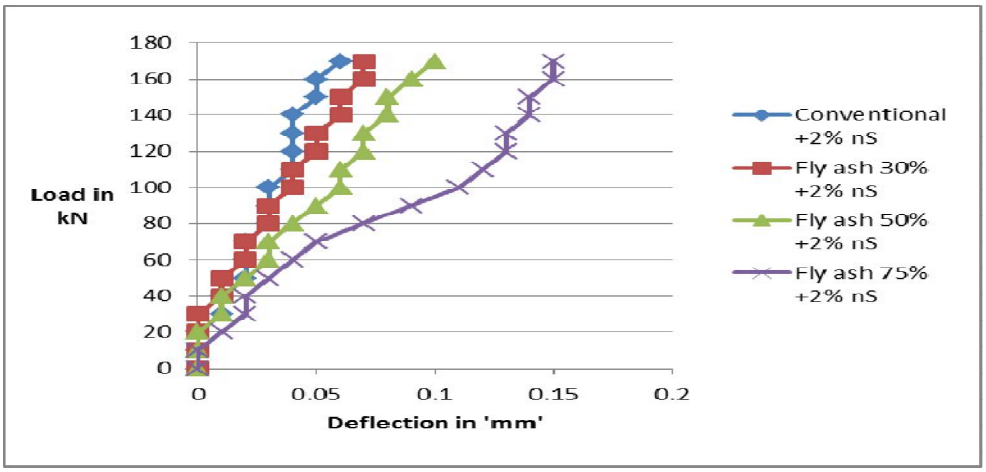

Figure 6 Load vs Deflection curve with Nano silica

4. MICROSTRUCTURE OF CONVENTIONAL CONCRETE AND NANO CONCRETE

Nano structure properties of concrete using SEM (Scanning Electron Microscope) was studied to know the internal structure of the concrete mix after adding Nano silica. The SEM pictures show morphological characteristics of internal structure of Nano concrete. Fig.7 shows the conventional concrete without Nano particles and Ettringite needle like structure is found. Fig.8 and Fig.9 show dense and well crystallized plates of (Ca $(OH)_2$ in concrete mixture. Calcium hydrate (CH) was converted to high reactivity Calcium Silicate Hydrate (CSH) gel by adding Nano silica in micron and Nano level respectively. The addition of Nano silica in concrete attains a better strength than the normal concrete because of its small size and denser C-S-H gel developed with high stiffness by character of homogeneous microstructure.

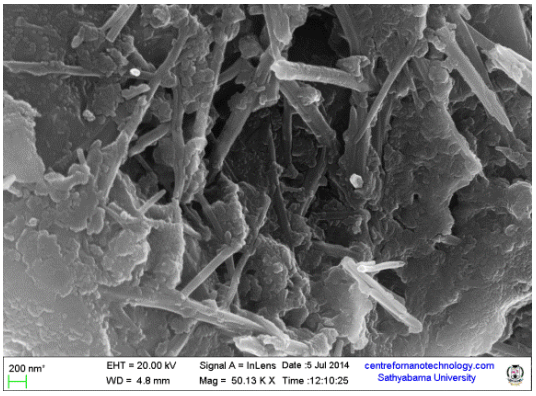

Figure 7 SEM image of concrete without Nano silica

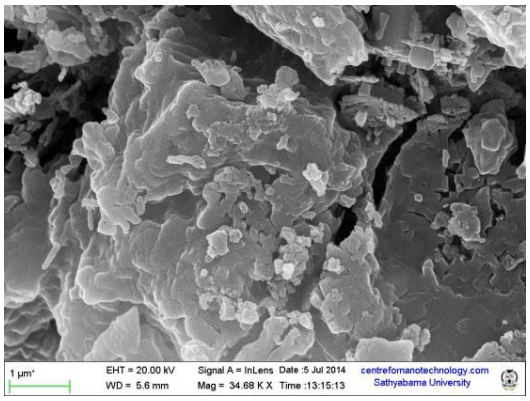

Figure 8 SEM image of concrete with Nano Silica (Micro level)

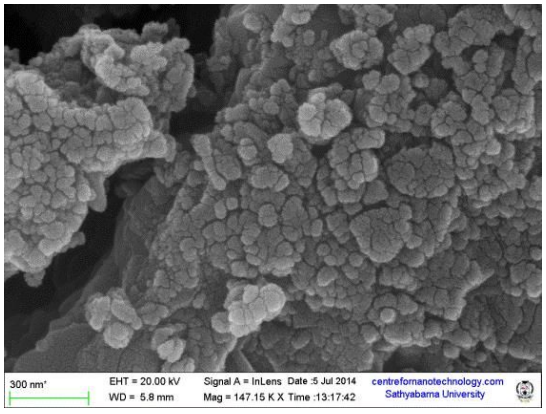

Figure 9 SEM image of concrete with Nano Silica (Nano level)

5. CONCLUSION

1. M30 grade of concrete with Nano silica increases the compressive strength by 44%, 54%, and 70% more than conventional concrete at 28 days, 56 days and 90 days respectively.

2. Compressive strength of concrete can be achieved by 11%, 24% and 36% more than conventional concrete at 28 days, 56 days and 90 days respectively, when adding 1% of Nano silica in concrete with the addition to 30% of cement replacement by fly ash. It is economical by means of reducing the cost of cement by using fly ash.

3. Split tensile strength of concrete achieved 46% more than conventional concrete by the addition of 1% Nano silica. Similarly 1% of Nano silica with cement replacement by 30% fly

ash increases 30% more strength than conventional concrete. Increasing the % of fly ash in concrete reduces the split tensile strength of concrete.

4. Modulus of elasticity of M30 grade of Nano concrete is 2.88 times more than conventional concrete. The strength properties of Nano concrete increases with age such as 56 and 90 days when fly ash is used for cement replacement.

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REFERENCES

[1] Flaga.K, Advances in materials applied in civil engineering, Journal of Materials Processing Technology 106, 2000, pp.173-183.

[2] Quercia. G, Spiesz.P, Husken.G, Brouwers H.J.H, SCC modification by use of amorphous Nano silica, Cement & Concrete Composites,2014,pp.69- 81.

[3] Rahel.Kh, Ibrahim, Hamid.R, Taha M.R, Fire resistance of high volume fly ash mortars with Nano silica addition. Construction and building materials 3, 2012,pp.779-786.

[4] Pacheco-Torgal.F, Miraldo.S, Ding.Y, J.A.Labrincha., Targeting HPC with the help of Nanoparticles: An overview, Construction and building materials 38,2013,pp.365-370.

[5] Monica.J. Hanus, Andrew T. Harris, Nanotechnology innovations for the construction industry, Progress in material science 58,2013,pp.1056-1102.

[6] Genedy shakhmenko, Inna Juhnevica, Aleksandrs Korjakins, Influence of sol- Gel Nano silica on hardening processes and physically Mechanical properties of cement paste, Procedia Engineering 57,2013,pp.1013-1021.

[7] Erdogan Ozbay, Ahmet Oztas, Adil Baykasoglu, Investigating mix proportions of high strength self-compacting concrete by using Taguchi method. Construction and building materials 23,2009,pp. 694-702.

[8] Prince Arul raj. G, Jemimah Carmichael.M, Effect of Nano-Fly ash on strength of concrete, International journal of civil and structural Engineering, Volume 2(2), 2011,pp. 475-482.

[9] Collepardi. M, Collepardi.S, Skarp.U and Troli.R Optimization of Silica fume, Fly ash and Amorphous Nano-Silica in Superplasticized High-performance concrete, 2004 Volume 201,pp.495-506.

[10] Luca Sorelli, Georgios Constantinides, Franz - Josef Ulm , François Toutle monde The Nano-mechanical signature of Ultra High Performance Concrete by statistical Nano indentation techniques, 2008 Vol-38,pp.1447-1456.

[11] Perumalsamy Balaguru and Ken Chong, Nanotechnology and concrete: Research Opportunities (2006), National Science Foundation, USA, Proceedings of ACI session on Nanotechnology of concrete: Recent developments and future perspectives: 2006,pp.15-27.

[12] Alireza Naji Givi, The effects of limewater on the properties of SiO_2 Nanoparticles binary blended concrete, Composites Part B: Engineering, (2011) Volume 42,2011,pp.562-569.

[13] Nazari Ali, Riahi, shadi, Splitting tensile strength of concrete using ground granulated blast furnace slag and SiO2 nanoparticles as binder, Energy and buildings,2011, Vol.43, pp.864-872.

[14] Byung Wan Jo, Chang Hyun Kim, Jae Hoon Lim ,Investigations on the Development of Powder Concrete with Nano-SiO_2, KSCE journal of civil engineering, 2007,pp.37-42.

[15] Said. A.M and Zeidan. M.S Enhancing the Reactivity of Normal and Fly Ash Concrete Using colloidal Nano-Silica, International concrete abstracts portal, special publication, Volume 267, pp. 75-86.

[16] Paramita Mondal, Surendra P.Shah, Laurence D. Marks, and Juan J. Gaitero, Comparative Study of the Effects of Microsilica and Nanosilica in Concrete, Transportation research record: 2010, pp. 6-9.

[17] Laila Raki , James Beaudoin, Rouhollah Alizadeh, Jon Makar and Taijiro Sato,Cement and Concrete Nanoscience and Nanotechnology, Materials, 2010,Vol – 3,pp.918-942.

[18] Ali Nazari, Shadi Riahi, The role of SiO_2 nanoparticles and ground granulated blast furnace slag admixtures on physical, thermal and mechanical properties of self-compacting concrete, Materials Science and engineering, 2011, pp.2149-2157.

[19] Arun Nishchal Guleria and Sandeep Salhotra, Effects of Silica Fume (Micro Silica or Nano Silica) on Mechanical Properties of Concrete: A Review. *International Journal of Civil Engineering and Technology,* 7(4), 2016, pp.345–357

[20] V. Nagendra, C. Sashidhar, S. M. Prasanna Kumar and N. Venkata Ramana GGBS and Nano Silica (NS) Effect on Concrete. *International Journal of Civil Engineering and Technology*, 7(5), 2016, pp.477–484.